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ORIGINAL PAPER

# Operational efficiencies and costs of an arm roll forwarder: A case study at Nasu in Tochigi Prefecture, Japan

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**Abstract:** We investigated a developed arm roll forwarder at Nasu in Tochigi Prefecture, Japan. An arm roll forwarder can only load a steel container that has been fully loaded with logs beforehand, and can later unload such a container. Such a forwarder can shorten the loading and unloading times and improve operational efficiency. We examined two operation systems with an arm roll forwarder and a forwarder. In the first system the loading was done with a grapple-loader. In the second system the loading was done with a processor. The loading times of an arm roll forwarder were significantly less than those of a forwarder. Because the optimal cycle times (excluding the waiting times for an arm roll forwarder) were significantly reduced, the costs of using an arm roll forwarder are lower, although the loading capacity was small and the hourly operation cost was high. The maximum operational efficiencies varied depending on forwarding distances. The second operation system with an arm roll forwarder exhibited the best operational efficiency within a 1,580-m forwarding distance, and beyond that distance it exhibited the highest operational efficiency when a forwarder was used. Similarly, the cost of operation of the system with an arm roll forwarder was the lowest within a 1,130-m forwarding distance, and beyond that distance the cost was the lowest when using the forwarder. Therefore, the arm roll forwarder is effective within a certain forwarding distance.

**Keywords:** arm roll forwarder; steel container; operational efficiency; cost; forwarding distance

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## Introduction

Logging by chainsaw felling and chainsaw or processor processing followed by forwarding, is widely used at small and large sites in the mountainous forests of Japan. However, a grapple equipped with a forwarder is usually small and the forwarder's operational efficiency for loading and unloading is low. An arm roll forwarder was developed to overcome this problem (Takahashi 2008; Goto and Takeda 2009; Yamasaki et al. 2011). An arm roll forwarder can only load a steel container that has been fully loaded with logs by processor beforehand, and it can only unload such a container afterward. Therefore, such a forwarder can shorten the loading time and improve loading operational efficiency significantly.

Takahashi (2008) reported that the average cycle time of an arm roll forwarder was 1,398 s per cycle at a 750-m forwarding distance, while that of a processor carrying out processing and direct loading was 1,764 s per cycle. Therefore, an arm roll forwarder was faster than a processor in this case. In contrast, the average cycle time of a forwarder was 2,184 s per cycle at a 750-m forwarding distance, around 800 s longer than for the arm roll forwarder. However, the cycle time of an arm roll forwarder was longer than for a processor carrying out processing and direct loading beyond a 1,070-m forwarding distance (Takahashi 2008). A processor must wait for an arm roll forwarder because a processor and an arm roll forwarder are to be operated simultaneously. However, the processor did not have to wait for the forwarder because the two were operated independently.

The arm roll forwarder investigated by Takahashi (2008) did not have a grapple-crane, and logs were dumped during the unloading operation. However, a grapple-loader was normally used for unloading in the operation system with an arm roll forwarder without a grapple-crane. Productivity and costs should be

estimated and compared not only for an arm roll forwarder or a forwarder itself, but also for the overall operation system. In this study we investigated operation systems at one site using an arm roll forwarder versus a forwarder, and compared their productivity and operating costs.

## Materials and methods

### Study site

The study site was in Yanome district, Nasu, Tochigi Prefecture, Japan (Fig. 1). The area of the study site was 29.36 ha and its stock was 9,395 $m^3$. The study site is a plantation forest consisting of 53-year-old Japanese cedar and Japanese cypress. A thinning operation was conducted in the study site. Thinned woods bucked into 3-m-long logs were forwarded to a landing. We evaluated systems for forwarding sites distant (610–780 m) from a landing, and nearby (100–410 m) a landing. The distant sites had Japanese cypress, and the nearby sites had Japanese cedar. Investigations were conducted from 8-10 November 2010.

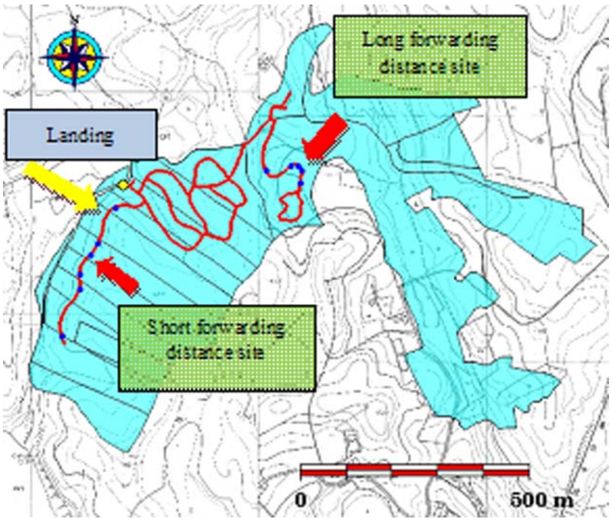


**Fig. 1 The study site**

### Operation system

We evaluated two operation systems that employed an arm roll forwarder (Fig. 2 and Tables 1 and 2). Operation system 1 included chainsaw felling, grapple-loader bunching, processor processing (delimbing and bucking), grapple-loader loading, arm roll forwarder forwarding, and mini-grapple unloading. Two steel containers were used. One was located on a loading site, and the other was located on an arm roll forwarder. Forwarding and unloading operations were conducted by the same operator, but other operations were conducted by other operators (there were five operators in total).

Operation system 2 included chainsaw felling, grapple-loader bunching, processor processing and direct loading, arm roll forwarder forwarding, and mini-grapple unloading. Forwarding and unloading operations were conducted by the same operator, but other operations were conducted by other operators (there were four operators in total). Operating costs could be reduced with this system because the grapple-loader was not necessary. However, if the processor processing and loading time increased, the operating costs would also increase. Therefore, one of our objectives was to compare the systems with and without the use of a grapple-loader.

**Fig. 2 An arm roll forwarder (up) and a forwarder (down)**

Another objective was to compare the forwarder with the arm roll forwarder. Operation system 1 was examined with an arm roll forwarder and a forwarder. The forwarder usually loaded and unloaded using a grapple-crane equipped with a forwarder. Therefore, operation system 2 that included chainsaw felling, grapple-loader bunching, processor processing, and forwarder loading, forwarding and unloading was also examined based on the results of Nakahata et al. (2011).

Costs included labor expenses (2,550 yen·$h^{-1}$) and machinery expenses (including maintenance, management, depreciation, and fuel and oil expenses). Machinery expenses were: chainsaw, 419 yen·$h^{-1}$; grapple-loader, 4,749 yen·$h^{-1}$; processor, 7,505 yen·$h^{-1}$; arm roll forwarder, 5,912 yen·$h^{-1}$; forwarder, 5,302

yen·h$^{-1}$; and mini-grapple, 2,588 yen·h$^{-1}$ (1 yen = 0.080 CNY on 18 June 2012).

**Table 1. Forwarder specifications**

| | Type | Weight | Size | | | | | | Engine | | Speed (km·h$^{-1}$) | | Loading capacity (kg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Length (mm) | Width (mm) | Height (mm) | Track width (mm) | Contact pressure (kPa) | Clearance (mm) | Displacement (mm) | Output (kW/rpm) | Low | High | |
| Arm roll forwarder | Iwafuji U-4SBRL | 5,630* | 5,510 | 2,140 | 2,545 | 500 | 20.9 | 370 | 4,329 | 80.9/2,200 | 0–7 | 0–10 | 3,800** |
| Forwarder | Iwafuji U-4SBG | 7,350 | 5,940 | 2,975 | 3,145 | 500 | 28.5 | 370 | 4,329 | 80.9/2,200 | 0–7 | 0–10 | 3,000 |

* without steel container; ** including steel container. Weight of steel container for 3–4-m-long log is 745 kg, for 2-m-long log is 670 kg, and for logging residues is 1,000 kg.

**Table 2. The operation system**

| | Felling | Bunching | Processing | Loading | Forwarding | Unloading | No. operators |
|---|---|---|---|---|---|---|---|
| Arm roll forwarder 1 | Chainsaw1 | Grapple-loader2 | Processor3 | Grapple-loader2 | Arm roll forwarder | Mini-grapple4 | Five |
| Arm roll forwarder 2 | Chainsaw1 | Grapple-loader2 | Processor3 | Processor3 | Arm roll forwarder | Mini-grapple4 | Four |
| Forwarder 1 | Chainsaw1 | Grapple-loader2 | Processor3 | Grapple-loader2 | Forwarder | Mini-grapple4 | Five |
| Forwarder 2 | Chainsaw1 | Grapple-loader2 | Processor3 | Forwarder | Forwarder | Forwarder | Four |

[1] Husqvarna 357XPG, [2] Hitachi Zaxis135US with Iwafuji GS90LJV, [3]Hitachi Zaxis135US with Iwafuji GP-35A, and [4] Caterpillar 305C CR with Iwafuji GS-50LJV.

## Results and discussion

Forwarder forwarding

Cycle time, productivity and cost are listed in Tables 3 and 4. Because the difference in the average forwarding distances between the distant (698.5 m) and nearby (314.9 m) sites for an arm roll forwarder was 380 m, the average travel time at the distant sites was twice as long as that of the nearby sites. The average cycle time of the distant sites was 300 s per cycle longer than that of the nearby sites. Optimal cycle time was estimated with outhaul, unloading container, loading container, inhaul and unloading. Productivity and costs were estimated for optimal cycle times. Productivity estimates for the distant and nearby sites were 11.8 and 15.6 m$^3$·h$^{-1}$, respectively. Costs were 718 and 544 yen·m$^{-3}$, respectively. Waiting times caused by the grapple-loader and the arm roll forwarder operating simultaneously are discussed later.

**Table 3. Cycle time (s) of the forwarder**

| Forwarder | | Outhauling | Unloading container | Loading container | Loading | Inhauling | Unloading | Others | Waiting | Cycle time | Optimal cycle time |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Arm roll forwarder | Long | 351 | 48 | 39 | – | 392 | 257 | 98 | 375 | 1,560 | 1,185 |
| | Short | 167 | 87 | 78 | – | 161 | 217 | 181 | 352 | 1,243 | 891 |
| Forwarder | Long | 415 | – | – | 599 | 438 | 330 | 0 | 0 | 1,782 | 1,782 |
| | Short | 235 | – | – | 620 | 154 | 352 | 0 | 0 | 1,361 | 1,361 |
| Forwarder 2* | | 232 | – | – | 822 | 194 | 519 | 0 | 0 | 1,767 | 1,767 |

Optimal cycle times were estimated with outhaul, unloading container, loading container, loading, inhaul, unloading, and others. *Nakahata et al. (2011)

**Table 4. Productivity and cost of the forwarder**

| | | Average forwarding Distance (m) | Average outhaul speed(m·s$^{-1}$) | Average inhaul speed(m·s$^{-1}$) | Average stem Volume (m$^3$/stem) | Averagelog volume (m$^3$/stem) | Forwarding volume (m$^3$/cycle) | Productivity (m$^3$·h$^{-1}$) | Hourly operation cost (yen·h$^{-1}$) | Cost (yen·m$^{-3}$) |
|---|---|---|---|---|---|---|---|---|---|---|
| Arm roll forwarder | Long | 698.5 | 2.0 | 1.8 | 0.35 | 0.22 | 3.88 | 11.8 | 8,462 | 718 |
| | Short | 314.9 | 1.9 | 2.0 | 0.35 | 0.25 | 3.85 | 15.6 | 8,462 | 544 |
| Forwarder | Long | 851.6 | 2.1 | 1.9 | 0.35 | 0.26 | 4.49 | 9.1 | 7,852 | 866 |
| | Short | 291.3 | 1.2 | 1.9 | 0.35 | 0.28 | 4.82 | 12.7 | 7,852 | 616 |
| \Forwarder 2* | | 390.0 | 1.7 | 2.0 | 0.16 | 0.13 | 4.57 | 9.3 | 7,852 | 843 |

Because the difference in the average forwarding distances between the distant (851.6 m) and nearby (291.3 m) sites for a forwarder was 560 m, the outhauling and inhauling times for the distant sites were two and three times longer than those of the nearby sites. The average cycle time of the distant sites was 400 s per cycle longer than that for the nearby sites. Productivity estimates for the distant and nearby sites were 9.1 and 12.7 $m^3 \cdot h^{-1}$, respectively. Costs were 866 and 616 yen·$m^{-3}$, respectively. The average forwarding distance, cycle time, productivity and cost of another operation system (forwarder 2) were 390 m, 1,767 s per cycle, 9.3 $m^3 \cdot h^{-1}$ and 843 yen·$m^{-3}$, respectively (Nakahata et al. 2011). These lie between estimates for the distant and nearby sites in our study of a forwarder.

The loading time of the arm roll forwarder was significantly reduced compared with that of a forwarder. However, the reduction in cycle time was small because of the waiting time. Because the optimal cycle time (excluding the waiting time of an arm roll forwarder) was significantly reduced, the costs of an arm roll forwarder were also reduced, although the loading capacity was small and the hourly operation cost was high.

### Processor processing

The cycle time, productivity and cost of a processor are listed in Table 5. Nakahata et al. (2011) derived the following equation to estimate the cycle time of a processor $CT_P$ (s/stem):

$$CT_P = 89V_l + 114 \quad (1)$$

Where, $V_l$ is the average log volume ($m^3$/stem). The cycle time was estimated at 136 s/stem by substituting the average log volume at our research site (0.25 $m^3$/stem) into Equ. 1. A processor evaluated by Nakahata et al. (2011) conducted piling using a grapple-loader. Therefore, our estimated cycle time of a processor (from Equ. 1), namely 136 s/stem, was longer than reported by Nakahata et al. (*ibid.*), namely 83 s/stem (Table 5). The optimal cycle time was estimated considering moving, grabbing, delimbing and bucking. Then, the productivity and cost were estimated at 11.7 $m^3$/h and 860 yen/$m^3$ from the optimal cycle time, respectively.

The cycle time, productivity, and the cost of processor processing and direct loading are listed in Table 6. The optimal cycle time of processor processing and direct loading, 57 s/stem, was shorter than that for processor processing only, 77 s/stem. Therefore, the productivity was higher and the cost was lower than with processor processing alone.

**Table 5. Cycle time, productivity, and cost of the processor**

| | | Moving (s/stem) | Grabbing (s/stem) | Delimbing and bucking (s/stem) | Others (s/stem) | Waiting (s/stem) | Cycle time (s/stem) | Optimal cycle time (s/stem) | Average log volume ($m^3$/stem) | Productivity ($m^3 \cdot h^{-1}$) | Hourly operation cost (yen·$h^{-1}$) | Cost (yen·$m^{-3}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Arm roll forwarder | Long | 3 | 19 | 43 | 7 | 7 | 79 | 72 | 0.22 | 11.0 | 10,055 | 914 |
| | Short | 8 | 17 | 41 | 6 | 3 | 75 | 72 | 0.25 | 12.5 | 10,055 | 804 |
| Forwarder | Long | 7 | 21 | 51 | 5 | 2 | 86 | 84 | 0.26 | 11.1 | 10,055 | 902 |
| | Short | 8 | 19 | 49 | 2 | 0 | 78 | 78 | 0.28 | 12.9 | 10,055 | 778 |
| | Average | 7 | 19 | 46 | 5 | 3 | 80 | 77 | 0.25 | 11.7 | 10,055 | 860 |

Optimal cycle times were estimated with moving, grabbing, delimbing, bucking, and others. Productivity and cost were estimated using optimal cycle time.

**Table 6. Cycle time, productivity, and cost of processor operation and direct loading**

| Moving (s/stem) | Delimbing and bucking (s/stem) | Waiting (s/stem) | Residue removal (s/stem) | Cycle time (s/stem) | Optimal cycle time (s/stem) | Average log volume (m3/stem) | Productivity ($m^3 \cdot h^{-1}$) | Hourly operation cost (yen·$h^{-1}$) | Cost (yen·$m^{-3}$) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 56 | 13 | 15 | 85 | 57 | 0.24 | 15.2 | 10,055 | 663 |

Delimbing and bucking included grabbing. Optimal cycle times were estimated considering moving, delimbing, and bucking. Productivity and cost were estimated using optimal cycle time

### Grapple-loader loading

The cycle time, productivity and cost of loading by grapple-loader are listed in Table 7. Forwarder forwarding and grapple-loader loading were carried out simultaneously. Therefore, the cycle times of forwarder forwarding and grapple-loader loading were nearly equal. The optimal cycle times for grapple-loader loading were 28 and 206 s per cycle shorter than those of forwarder forwarding at nearby and distant sites, respectively. Therefore, the optimal cycle time of grapple-loader loading was almost equal to that of forwarder forwarding at nearby sites. The cycle time of grapple-loader loading with a forwarder was longer than that with an arm roll forwarder. Therefore, it is clear that an

arm roll forwarder in this system was effective.

**Table 7. Cycle time, productivity, and cost of grapple-loader loading**

| | Moving (s/cycle) | Steel container moving (s/cycle) | Loading (s/cycle) | Steel container loading support (s/cycle) | Waiting (s/cycle) | Residue removal (s/cycle) | Piling (s/cycle) | Cycle time (s/cycle) | Optimal cycle time (s/cycle) | Forwarding volume ($m^3$/cycle) | Productivity ($m^3 \cdot h^{-1}$) | Hourly operation cost (yen$\cdot h^{-1}$) | Cost (yen$\cdot m^{-3}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Arm roll forwarder | | | | | | | | | | | | | |
| Long | 48 | 170 | 730 | 31 | 149 | 135 | 66 | 1,329 | 979 | 3.88 | 14.3 | 7,299 | 512 |
| Short | 25 | 182 | 629 | 27 | 123 | 105 | 38 | 1,129 | 863 | 3.85 | 16.1 | 7,299 | 454 |
| Forwarder | | | | | | | | | | | | | |
| Long | 45 | – | 570 | – | 249 | 366 | 250 | 1,480 | 615 | 4.49 | 26.3 | 7,299 | 278 |
| Short | 79 | – | 623 | – | 190 | 140 | 253 | 1,285 | 702 | 4.82 | 24.7 | 7,299 | 295 |

Optimal cycle times were estimated with moving, steel container moving, loading, and steel container loading support. Productivity and cost were estimated using optimal cycle time.

### Operation systems

The cycle time of chainsaw felling $CT_C$ (s/stem) was estimated using the following equation (Nakahata et al. 2011):

$$CT_C = 136 \times V + 111 \quad (2)$$

Where, $V$ is the average stem volume ($m^3$/stem). The cycle time was estimated at 159 s/stem by substituting the average stem volume at our research site (0.35 $m^3$/stem) into Equ. 2. Chainsaw felling and grapple-loader bunching were carried out simultaneously. Therefore, the cycle time of grapple-loader loading was the same as that of chainsaw felling.

The cycle time, productivity and cost of operation system 1 with an arm roll forwarder were 548 s/stem, 1.6 $m^3 \cdot h^{-1}$ and 4,230 yen$\cdot m^{-3}$, respectively, at distant sites, and 511 s/stem, 1.8 $m^3 \cdot h^{-1}$, and 3,853 yen$\cdot m^{-3}$, respectively. At nearby sites, cycle time, productivity and cost of operation system 2 with an arm roll forwarder were 471 s/stem, 1.9 $m^3 \cdot h^{-1}$ and 3,604 yen$\cdot m^{-3}$, respectively, at distant sites, and 434 s/stem, 2.1 $m^3 \cdot h^{-1}$ and 3,171 yen$\cdot m^{-3}$, respectively, at nearby sites (Table 8). Therefore, the cycle time of operation system 1 with an arm roll forwarder was longer, the productivity was lower, and the cost was higher than for operation system 2 with an arm roll forwarder.

The cycle time, productivity and cost of operation system 1 with a forwarder were 593 s/stem, 1.5 $m^3 \cdot h^{-1}$ and 4,630 yen$\cdot m^{-3}$, respectively, at distant sites, and 536 s/stem, 1.7 $m^3 \cdot h^{-1}$, and 4,065 yen$\cdot m^{-3}$, respectively, at nearby sites, while those of operation system 2 with a forwarder were 551 s/stem, 1.6 $m^3 \cdot h^{-1}$, and 4,179 yen$\cdot m^{-3}$, respectively (Table 8). Therefore, the values of operation system 2 with a forwarder were between those of operation system 1 with a forwarder at nearby and distant sites.

The cycle time of operation system 1 with an arm roll forwarder was shorter, the productivity higher, and the cost lower than for operation system 1 with a forwarder. Therefore, an arm roll forwarder with operation system 1 was also effective.

**Table 8. Cycle time, productivity, and cost of operation system**

| | Cycle time (s/stem) | Productivity ($m^3 \cdot h^{-1}$) | Cost (yen$\cdot m^{-3}$) |
|---|---|---|---|
| Arm roll forwarder 1 | | | |
| Long | 548 | 1.6 | 4,230 |
| Short | 511 | 1.8 | 3,853 |
| Arm roll forwarder 2 | | | |
| Long | 471 | 1.9 | 3,604 |
| Short | 434 | 2.1 | 3,171 |
| Forwarder 1 | | | |
| Long | 593 | 1.5 | 4,630 |
| Short | 536 | 1.7 | 4,065 |
| Forwarder 2* | 551 | 1.6 | 4,179 |

*Nakahata et al. (2011)

### Operation system and forwarding distance

The forwarding time, rate and volume for each operation system are listed in Table 9. The equation to estimate the cycle time of a forwarder was developed using the forwarding distance. The forwarding distance to balance between cycle times of forwarder forwarding and grapple-loader loading or processor processing and direct loading was also estimated. The cycle time of grapple-loader loading was longer than that for forwarder forwarding within this estimated forwarding distance, while the cycle time of grapple-loader loading was shorter than that for forwarder forwarding beyond this estimated forwarding distance. Because the grapple-loader loading and forwarder forwarding were simultaneously operated, the cycle time of forwarder forwarding would be the same as that of grapple-loader loading within this estimated forwarding distance, while the cycle time of grapple-loader loading would be the same as that of forwarder forwarding beyond this estimated forwarding distance. The cycle time, productivity and cost of operation along forwarding distances were estimated using these cycle times (Figs. 3–5).

**Table 9. Forwarding time, speed, and volume**

| | Optimal cycle Time (s/cycle) | Outhaul time (s/cycle) | Inhaul time (s/cycle) | Forwarding distance (m/cycle) | Outhaul speed (m/s) | Inhaul speed (m/s) | Forwarding volume (m3/cycle) | Time besides moving (s/cycle) | Cycle time CTF (s/cycle) | Optimal Cycle time[1] (s/cycle) | Forwarding distance[2] (m/cycle) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Arm roll forwarder | | | | | | | | | 1.1*Lf*+510 | | |
| System 1 | 1,016 | 246 | 260 | 442.8 | 1.8 | 1.7 | 3.87 | 510 | 1.1*Lf*+510 | 913 | 352 |
| System 2 | 1,016 | 246 | 260 | 442.8 | 1.8 | 1.7 | 3.87 | 510 | 1.1*Lf*+510 | 882 | 326 |
| Forwarder | | | | | | | | | | | |
| System 1 | 1,552 | 317 | 283 | 546.0 | 1.7 | 1.9 | 4.67 | 952 | 1.1*Lf*+952 | 669 | – |
| System 2 | 1,767 | 232 | 194 | 390.0 | 1.7 | 2.0 | 4.57 | 1,341 | 1.1*Lf*+1,341 | – | – |
| Three containers | | | | | | | | | | | |
| System 1 | 913 | 246 | 283 | 442.8 | 1.8 | 1.7 | 3.87 | 407 | 1.1*Lf*+407 | 913 | 442 |
| System 2 | 913 | 246 | 194 | 442.8 | 1.8 | 1.7 | 3.87 | 407 | 1.1*Lf*+407 | 882 | 416 |

[1]Optimal cycle time of grapple-loader loading or processor processing and direct loading. [2]Forwarding distance balanced between cycle time of forwarder forwarding and grapple-loader loading or processor processing and direct loading. *Lf*: forwarding distance (m).

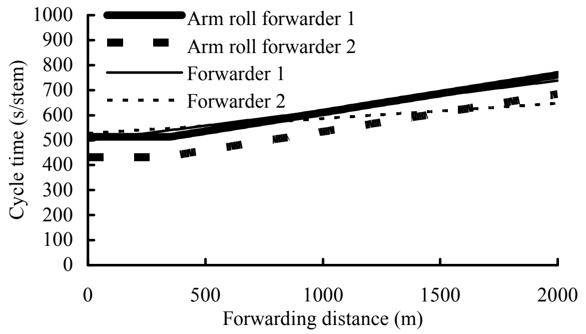


**Fig. 3 Cycle time of the operation system.**

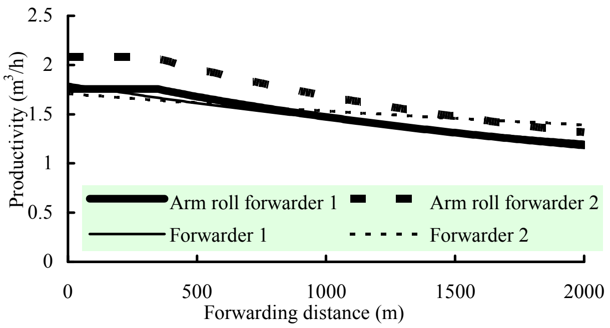


**Fig. 4 Productivity of the operation system.**

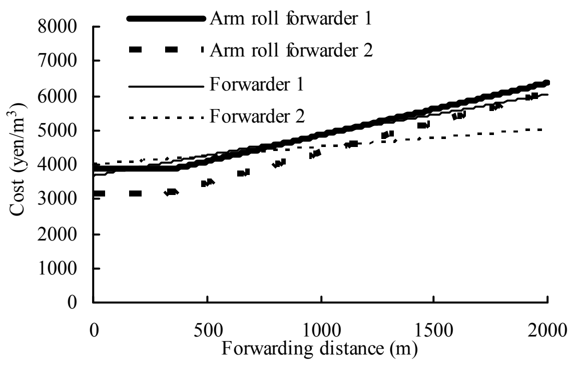


**Fig. 5 Operating cost of the operation system.**

Cycle time, productivity and cost vary depending on forwarding distance. The cycle time of operation system 2 with an arm roll forwarder was the shortest within a 1,580-m forwarding distance, and the cycle time of operation system 2 with a forwarder was the shortest beyond the 1,580-m forwarding distance. Cycle times of operation system 1 with an arm roll forwarder and a forwarder were longer than those of operation system 2 due to more machines and subsequently more waiting times. Similarly, the productivity of operation system 2 with an arm roll forwarder was highest within a 1,580-m forwarding distance, and the productivity of operation system 2 with a forwarder was highest beyond a 1,580-m forwarding distance. The productivity of operation system 1 with an arm roll forwarder and a forwarder was also lower than that of operation system 2. Similarly, the cost of operation system 2 with an arm roll forwarder was the lowest within a given forwarding distance. However, this forwarding distance was 1,130 m, and it differs from those for the cycle time and productivity due to different machinery expenses. The cost of operation system 2 with a forwarder was the lowest beyond a 1,130-m forwarding distance.

### Operation system with three steel containers

We used two containers in our research. Therefore, loading could be conducted separately from forwarding. However, unloading was done with a mini-grapple by the operator of an arm roll forwarder, and the machine had to wait for the unloading operation to be completed. If one more container was used, unloading could be conducted separately from forwarding, thus the cycle time of the arm roll forwarder could be shortened. However, an additional operator would be needed for unloading. Therefore, the cycle time, productivity, and cost of an arm roll forwarder with different numbers of containers were estimated and compared.

Unloading was done separately from forwarding, but unloading a fully loaded container and loading another empty container at the landing were necessary when using three containers. Therefore, the cycle time of forwarding was reduced during the unloading of logs (234 s per cycle) and increased during the unloading of a fully loaded container and the loading of another

empty container (70 and 61 s per cycle, respectively). These values were assumed to be the same as those of the average times for unloading an empty container and loading a fully loaded container, respectively. As a result, the cycle time of an arm roll forwarder was reduced by 103 s per cycle (Table 9). However, the cycle time of the operation system with three containers was longer, productivity was lower, and cost was higher than with two containers due to higher machinery costs (234 yen/h for an additional steel container) and more operators (Fig. 6).

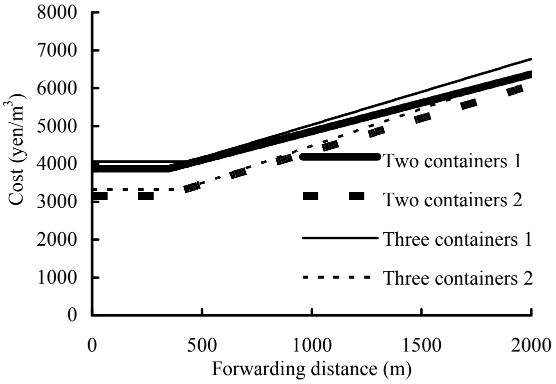


**Fig. 6 Operating cost by container number**

## Conclusion

A recently developed arm roll forwarder was investigated in this study. When this equipment was used, the maximum operational efficiencies of operation systems changed depending on forwarding distances. Operation system 2 with an arm roll forwarder exhibited the best operational efficiency within a 1,580-m forwarding distance, and beyond that distance, it exhibited the highest operational efficiency when a forwarder was used. Similarly, the cost of operation system 2 with an arm roll forwarder was the lowest within a 1,130-m forwarding distance, and beyond that distance, the cost was the lowest when a forwarder was used. Therefore, we conclude that use of an arm roll forwarder is effective within a certain forwarding distance.

In addition to the steel container for 3–4-m-long logs that was used in this study, an arm roll forwarder can be used with a steel container for 2-m-long logs and for forest biomass. These containers could be used to extract small-sized thinned woods and logging residues such as tops and branches. Furthermore, they could be used with an arm roll truck without unloading logs and forest biomass from the containers of an arm roll forwarder and without loading them to containers of an arm roll truck. This would improve productivity and reduce the operating costs of extracting small-sized thinned woods and forest biomass, for which extraction productivity was usually low and costs were usually high. However, no studies were conducted to examine the extraction of small-sized thinned woods or forest biomass with an arm roll forwarder. Therefore, the next study will investigate and analyze the productivity and operational costs of this type of extraction.


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